NPOESS Cross-track Infrared and Microwave Sounder Suite (CrIMSS) EDR Retrieval Algorithm and its Performance Assessment

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Abstract

This paper presents a brief description and the current performance estimate of the Environmental Data Records (EDR) retrieval algorithm for the Cross-track Infrared and Microwave Sounder Suite (CrIMSS) to fly on the NPP/NPOESS satellites.

Summary

The Cross-track Infrared and Microwave Sounder Suite (CrIMSS) will be flying on the National Polar Orbiting Environmental Satellite Systems (NPOESS) and its Preparatory project (NPP) satellites. It is designed to produce three Environmental Data Records (EDR) products, i.e., the Atmospheric Vertical Temperature Profile (AVTP), Atmospheric Vertical Moisture Profile (AVMP) and Atmospheric Vertical Pressure Profile (AVPP). They are respectively defined as layer-averaged atmospheric temperature, layer-averaged atmospheric water vapor mass mixing ratio, and atmospheric pressure at specified altitudes above surface.

The suite consists of two instruments: the Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS). With its more than 1000 channels and fine spectral resolutions, CrIS will provide improved measurements of the temperature and moisture profiles in the atmosphere. The ATMS will extend the measurement capability to cloudy and even overcast conditions when the infrared sensor is severely limited. By combining the two, CrIMSS is expected to produce high quality and all weather EDR products to be used by increasingly sophisticated weather forecast models.

The CrIMSS EDR retrieval algorithm was developed by Atmospheric and Environmental Research, Inc. (AER). It is an iterative physical retrieve algorithm that simultaneously estimates the geophysical states of both the atmosphere and the surface from the infrared and microwave radiances measurements. It combines a fast and accurate radiative transfer model (OSSRTM), a classical constrained inversion model, and a heritage cloud-clearing algorithm to meet the stringent requirements on both latency and accuracy. The algorithm is normally executed on two distinct stages to fully exploit the radiometric information contained in the microwave and infrared radiance data. In the first stage, retrievals are performed using only the ATMS data and on CrIS Field of Regard which consists of an array of 3x3 CrIS Field of Views (FOV). Since the microwave sensor is not much affected by clouds, this step produces a reasonable estimate of the atmosphere and surface states, which is required to initiate the second stage processing and to estimate and compensate for the cloud contamination in the infrared radiance data (cloud-clearing). In the second stage, the inversion is formed combining both the microwave and infrared data and on either a single CrIS FOV or a cluster of CrIS FOVs depending on cloudiness of the scene. Cloud clearing is a key component of the second stage processing, and accuracy of the cloud-cleared infrared radiance determines the final quality of its output. The cloud-clearing algorithm adopted by the CrIMSS algorithm has consistently shown good performance on both real and simulated data, and the combined retrieval results usually have much improved quality over the microwave only first stage retrieval results.

The CrIMSS EDR retrieval algorithm had been tested and verified to meet EDR performance requirements by AER and the CrIS sensor subcontractor before it was delivered to the NPOESS prime contractor, Northrop Grumman Space Technology (NGST). Prior to the algorithm being converted to operational algorithm, it was modified to add the capability of producing the total Ozone Column product using the 9.6μm ozone band. The algorithm was then independently tested using NGST's global test data which were generated for verifications of the EDR performance of all NPOESS primary sensors.

The test data used to test the CrIMSS EDR algorithm consisted of 12 days of global, day and night measurements. There was one dataset for each month to cover seasonal variability of the environmental conditions. The data were sparsely re-sampled to reduce data volume but essentially maintain spatial and temporal coverage. As a result of the re-sampling, each data set corresponds in size to about 1/3 of an orbit's worth of full resolution data. The atmospheric attributes came from sources including NCEP AVN reanalysis (temperature, moisture, ozone, cloud water), UARS climatology database (moisture, ozone) and CIRA-86 climatology database (temperature). Cloud data were simulated using the Northrop Grumman Electronic System's CSSM model with input from NCEP cloud liquid water. Surface properties were simulated using information from NCEP (temperature, wind speeds) and PRA database (emissivity). To avoid incestuous testing, we have complied a large diversified training dataset derived from the ECMWF diversified dataset, the NOAA88 dataset, the ASTER and MODIS Spectral Emissivity Libraries, and NGST's own global test data sets. This training data set was used to estimate the mean and covariance of the atmospheric and surface state parameters, and to derive the Empirical Orthogonal Functions (EOF) that were used to reduce the dimensionality and to enhance the numerical performance of the inversion algorithm.

To simulate the CrIS and ATMS radiance, we have employed the AER's Optical Spectral Sampling Radiative Transfer Models (OSSRTM). Various sensor effects including noise, spectral uncertainty, calibration uncertainty, jitter and etc. were simulated in an effort to emulate realistic sensor performances.

The test of the CrIMSS EDR algorithm was focused on two key NPOESS EDRs, AVTP and AVMP. The measurement uncertainty requirements were stratified according to the cloudiness of the scene. A scene is classified as cloudy if its cloud coverage equals to or is larger than 50%, otherwise it is classified as clear if the cloud coverage is less than 50%. The test results, together with the performance requirements, were summarized in Table 1 and 2 for AVTP and AVMP respectively. In these tables, “Specified Values” are our system performance requirement specifications, “Threshold values” are the Integrated Operational Requirements Document (IORD) performance threshold values, “Estimated Values” are the worst measurement uncertainty estimates for each of the vertical stratifications, and “Margin” is the percentage difference between the “Estimated Values” and the “ Specified Values”.

Table 1 AVMP performance requirements and current estimates

Paragraph	Subject	Specified Values	Threshold Values	Estimated Values	Margin
40.2.1-9	1. Clear, Surface to 600 mb	14.10%	20% (or 0.2g/kg)	8.00%	43.30%
40.2.1-10	2. Clear, 600 mb to 300 mb	13.80%	35% (or 0.1g/kg)	7.40%	46.40%
40.2.1-11	3. Clear, 300 mb to 100 mb	11.7% (or 0.05g/kg)	35% (or 0.1g/kg)	0.008k/kg	84%
40.2.1-12	4. Cloudy, Surface to 600 mb	15.80%	20% (or 0.2g/kg)	12.50%	20.90%
40.2.1-13	5. Cloudy, 600 mb to 300 mb	17.10%	40% (or 0.1g/kg)	10.50%	38.60%
40.2.1-14	6. Cloudy, 300 mb to 100 mb	16.4% (or 0.05g/kg)	40% (or 0.1g/kg)	0.015g/kg	70%

Table 2 AVTP performance requirements and current estimates

Paragraph	Subject	Specified Values	Threshold Values	Estimated Values	Margin
40.2.2-26a	1. Clear, Surface to 300 mb	0.9 K / 1 km Layer	1.6K	0.77K	14.4%
40.2.2-27	4. Clear, 300 mb to 30 mb	0.98 K / 3 km Layer	1.5K	0.7K	28.6%
40.2.2-28a	5. Clear, 30 mb to 1 mb	1.45 K / 5 km Layer	1.5K	1.25K	13.8%
40.2.2-29	8. Clear, 1 mb to 0.5 mb	3.5 K / 5 km Layer	3.5K	1.73K	50.6%
40.2.2-30	10. Cloudy, Surface to 700 mb	2.0 K / 1 km Layer	2.5K	1.30K	35%
40.2.2-31	11. Cloudy, 700 mb to 300 mb	1.4 K / 1 km Layer	1.5K	0.98K	30%
40.2.2-32	12. Cloudy, 300 mb to 30 mb	1.3 K / 3 km Layer	1.5K	0.90K	30.8%
40.2.2-33a	13. Cloudy, 30 mb to 1 mb	1.45 K / 5 km Layer	1.5K	1.22K	15.9%
40.2.2-34	16. Cloudy, 1 mb to 0.5 mb	3.5 K / 5 km Layer	3.5K	1.78K	49.1%

From these two Tables it can be seen clearly that AVTP and AVMP meet the stringent performance requirements under both clear and cloudy conditions and at all altitudes, usually with significant amount of margin. For AVTP, the margin ranges from 13.8% to 50.6% under clear condition, and from 15.9% to 49.1% under cloudy condition. AVMP has even larger margin, ranging from 43.3% to 84% under clear condition and from 20.9% to 70% under cloudy condition respectively. Since all of our system performance requirements are either the same as or more stringent than the IORD thresholds, it shows that these two key NPOESS EDR products are estimated to meet or exceed the minimum requirements imposed by the user community.

It should be pointed out that, in spite of the great effort that NGST has made in generating the test data, their quality was inevitably limited by a number of factors including errors in the models, certain simplifications in the environmental conditions, and uncertainty in predicting the actual sensor performance. As such, using the simulated test data may under- or most likely over-estimate the true performance of the CrIMSS EDR algorithm. Therefore, the test results as summarized above stand for our current best estimate of the CrIMSS algorithm's performance, and should not be assumed to be the actual EDR quality of the operational data products that will be quantified in the post launch Cal/Val effort.